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POLICY COMPONENTS OF ARMS COMPETITIONS

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ABSTRACT

The purpose of this paper is to suggest and justify a simple approach to arms competitions, wherein arms competitions are viewed as disaggregated competitions between pairs of weapons systems for the execution of mutually incompatible policy goals. This approach is derived from a decision theoretic model of armament choice, wherein military force level decision makers make trade offs between alternative strategies of weapons deployment for the achievement of national foreign policy objectives. Data representing a cross-section of the US and USSR military arsenals is employed in a quasi-first difference two stage least squares analysis to evidence the propositions of the model and this approach.

INTRODUCTION

Since the pioneering work of Lewis Richardson, the study of arms races has formed a central part of the formal research in international relations.¹ Much of this work, however, has been disappointing; the statistical results have been rather unimpressive. The research reported in this paper is based on the premise that a major reason for these poor results is an inappropriate use of aggregation. Employing a decision theoretic framework — one which is not inconsistent with the rational actor, bureaucratic and organizational paradigms of political science — this paper develops a testable model of arms races which makes explicit the relation of arms growth to the achievement of a nation's foreign policy goals, and, moreover, yields stronger statistical results than much of the previous work in this field. Implicit in this approach is an intriguing counter-intuitive proposition: that arms control can itself be a cause of arms races.

PREVIOUS RESEARCH

The model formulated by Richardson is essentially a descriptive model, its primary contribution is that it encompasses much of our intuition about the causes and development of arms competitions. It posits arms races as competition between two mutually distrustful nations, wherein military budget appropriations

or military buildups by one nation are answered in-kind by the competing nation(s). According to this model competitive increases continue indefinitely or until abated by the wealth limits of the competing nations or by war.

The most plausible operationalization of the Richardson model is as a difference equation (equation 1). This formulation describes nations X's and nations Y's stock of weapons (or military budgets) at time t (X_t and Y_t respectively) as a function of both their own previous stock of weapons (X_{t-1} and Y_{t-1} respectively) and their adversary's previous stock of weapons (Y_{t-1} and X_{t-1}):

$$\begin{aligned} X_t &= \alpha X_{t-1} + \beta Y_{t-1} + c \\ Y_t &= \delta X_{t-1} + \gamma Y_{t-1} + f \end{aligned} \quad (1)$$

$\beta, \delta > 0 \quad \text{and} \quad \alpha, \gamma < 0$

The primary problem with this model arises when trying to estimate it as it is not clear what X and Y should stand for in the arms race context. Richardson thought them to be measures of the "total armed might" of the two mutually distrustful countries, and later tested the model with yearly defense budgets as proxies for X and Y. Most subsequent analyses have also employed defense budgets (see Chatterjee, 1974; Lambelet, 1976; Ruloff, 1975; Taagepera, Shiffler, Perkins, and Wagner, 1975). The model has further been applied to modern treatments of armament races in the missile age (see

Burns, 1959; Boulding, 1961; Brito and Intriligator, 1977; Intriligator and Brito, 1976; Luterbacher, 1976; McGuire, 1965, 1977; Saaty, 1968; and Taagepera, 1976). It should be noted that many of these later studies applied the Richardson model to stocks of weapons rather than to defense budgets.

The interpretation of defense budgets as a nation's "total armed might" is not entirely unreasonable, as increases in military budgets necessarily precede increases in "total armed might." However, as evidenced in many of the above listed studies, such a proxy gives no indication of the putative arms competition between the two superpowers. Indeed, these previous investigations have found little support for the existence of Richardson arms races. Many scholars argued that the data employed (military budgets) was too clumsy to allow estimation of often small incremental changes in "total armed might." Indeed, aggregate measures such as budgets could well mask small incremental changes in weapons systems and there is no reason to expect total military budgets between two (or more) competing nations to be linked in a Richardson (or any other) fashion.

But the analysis herein will argue that the problem is more fundamental and arises from the use of aggregate data for the study of arms races. If many individual (disaggregated) arms races occur simultaneously between two countries, they may all be correlated, or they may "heat up" and "cool down" independently. In the former case, one would observe the classical sort of aggregate arms race typically considered in the prevailing literature. In the latter

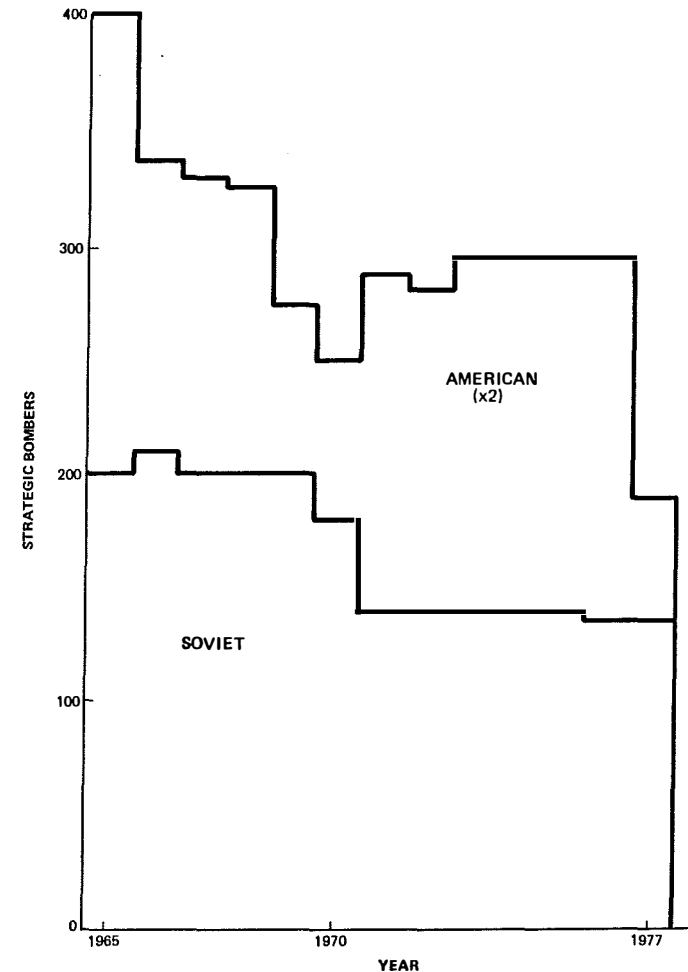
case, races related to various policy conflicts might "cancel out," in which case aggregate arms stocks or military expenditures are constant, even though strenuous weapons competition is actually occurring.

As indicated earlier, other scholars have examined the Richardson process through an analysis of the total stocks of weapons possessed by both sides of a competing pair of nations. Such an analysis, it was thought, might capture the subtle year-to-year changes in armaments which we expect to observe. However, these approaches were often merely a misapplication of disaggregated data, a misapplication brought about by the poor conceptualization inherent in the Richardson model. Such armament studies have frequently centered upon competitions between complementary weapons as exemplified in Figure 1. Figure 1 depicts Soviet and American stocks of manned strategic bombers, and registers the perceived decrease in American and Soviet bomber strength. However, as is true of many of the earlier mentioned disaggregative studies it exemplifies, no arms competition is evident in Figure 1.

FIGURE 1 ABOUT HERE

Stated most boldly, the basic aggregation problem inherent in the Richardson formulation derives from the fact that different weapons systems possess different policy characteristics.² Each weapons system, whether it be a Marine Corps Infantry Battalion or a MX missile squadron, has a policy mission for which it was designed

FIGURE 1
SOVIET AND AMERICAN STRATEGIC BOMBERS
(NOTE DIFFERING SCALES)



and produced to fulfill. To be sure, such systems are often multipurpose, but the recognition of such policy missions is central to understanding and defining arms competitions. The Richardson formulation, by not explicitly considering these policy characteristics of weapons systems, is unable to discriminate between which groups of weapons we should (and should not) expect to observe competition. By employing a decision theoretic approach this paper will seek to incorporate the policy characteristics of weapons into the resulting theory of arms competition.

A DECISION-THEORETIC APPROACH TO ARMS COMPETITION

In the previous section it was argued that the terms of the Richardson arms race equations have been poorly operationalized. In this section it will be suggested that, to the extent that nations engage in arms races, it does not seem likely that they operate at either aggregate levels (total defense expenditures) or at complementary disaggregations (e.g., bombers against bombers); to the extent that they race at all, it seems more likely that nations procure arms which are best suited for off-setting an adversary's recent arms acquisitions (e.g. stepped up bomber deployment by one nation will trigger new deployment of interceptors by the nation's adversary). This, it will be shown, is the result of rational actions by cost conscious decision makers. The mathematical formulation which follows establishes this result and derives the basis for the estimation in the following section.

The "'total armed might'" of a nation is a direct extension of that nation's foreign policy objectives and its overall strategic doctrine. These foreign policy objectives dictate the size and shape of the military force a nation will develop. A nation's strategic doctrine identifies the types of responses, missions, and tasks its military force must be designed to fulfill. Each weapons system procured then fulfills a specific policy mission as necessitated by the needs related to the nation's strategic doctrine.

For example, one American foreign policy objective is the prevention of nuclear conflict. A strategic doctrine developed relative to this objective is mutual deterrence. Specific weapons developed to fulfill policy missions under this doctrine are land based ICBM's, manned strategic bombers, and sea-based SLBM's. Each of which has a policy mission, i.e. that of inflicting (or threatening to inflict) a nuclear strike on point targets.

Nations derive political gain from the use, or potential use, of their "'total armed might,'" in accordance with their strategic doctrine.³ The basic behavioral postulate of the decision theoretic model to be put forth here is that military decision makers select weapons systems and procure armaments in such a manner so as to maximize their capability to pursue their nation's foreign policy goals. Such choices, of course, are subject to their nation's doctrinal, production, budgetary, and technological constraints. Given this behavioral assumption, I will define a set of refutable hypotheses relating arms race behavior and arms control to the

decision calculus just mentioned.

More formally, the behavioral assumption we posit is that a military decision maker engages in some sort of constrained maximizing behavior, the objective of which (for the two nation case A and B) is to maximize

$$\Pi^A(q_1, \dots, q_n, x_1, x_2, w_1, \dots, w_n) \quad (2)$$

where q_1, \dots, q_n represent weapons allocations for country A, given a set of specific foreign policy goals; x_1 , and x_2 represent inputs to the production of the above weapons systems; w_1, \dots, w_n represent the weapons allocations chosen by an adversary country B, given its own set of foreign policy goals; and $\Pi^A(-)$ represents the decision-makers political gain or profit from deploying q_1, \dots, q_n . This maximization is subject to the production and technology constraints inherent in nation A's economy which we will summarize as the implicit production constraint

$$F(q_1, \dots, q_n, x_1, x_2) = 0 \quad (3)$$

Thus I postulate each nation maximizes its own political gain, $\Pi(-)$, by selecting, in an optimal fashion, the deployment levels for each weapons system in its choice set, q_1, \dots, q_n , and the employment levels of productive inputs to armament manufacture, x_1 and x_2 , given their policy objectives and with respect to the choices of their adversary, $w_1 \dots w_n$. This maximization is performed with respect to q and x , the armament levels deployed and the production inputs employed

taking w , the adversary's armament level, as a parameter.

The approach outlined herein does not assume or depend on any formulation of governmental behavior. The model is consistent with, or at least not inconsistent with, the rational actor, bureaucratic or organizational frameworks developed by Allison.⁴ To be sure, the decision calculus is most readily appreciated as a two-person (nation) model and as such fulfills a rational actor framework of government. However, the interactions of various bureaucracies, or the consequences of standard operating procedures can result in actions which taken altogether appear as if the bureaucracy or organization was acting to maximize political gain as asserted.

A necessary consequence of the behavior assumed above in equations 2 and 3 is that the first order partial derivatives of the following Lagrangian equal zero:

$$L = \sum_j \Pi_j + \lambda F$$

where λ is the Lagrange multiplier. Employing a set of very general assumptions concerning government behavior and arms growth (see McCubbins, 1979), and applying well-known comparative statics techniques we can derive several testable hypotheses concerning arms competition. These propositions follow directly from the maximization in equation 2, performed individually and independently by each nation.

The refutable hypothesis which concerns us here indicates between which groups of weapons we should (and should not) expect to

observe competition for nations with conflicting foreign policy goals:

RH: Arms competitions develop only between weapons systems which are endowed with conflicting policy missions by their nation's strategic doctrine and goals.

Formally, RH states that the rate of change of the j^{th} weapons system for nation A, q_j , with respect to changes in the k^{th} weapons system, w_k , for nation B is positive if the weapon's policy tasks are incompatible options for each other ($j=k$) and is zero if the weapons are non-competitive options ($j \neq k$) for each other (McCubbins, 1979, p. 5-16):

$$\frac{\partial q_j}{\partial w_k} \begin{matrix} > 0 & \text{if } j=k \\ = 0 & \text{if } j \neq k \end{matrix} \quad (4)$$

The model thus makes explicit the relation of arms growth to the achievement of foreign policy goals by the military force level decision makers. The hypothesis suggests that arms races should be viewed as competitions between pairs of weapons systems for the achievement of incompatible policy goals, and not as competitions between the aggregate "armed might" of two mutually distrustful nations.

ESTIMATION

The basic hypothesis to be examined here is that arms competitions, between two reciprocally antagonistic countries, occurs only between weapons systems possessed of mutually incompatible policy goals. The

corollary to be examined is that arms competitions will not occur between weapons systems possessed of congenial policy goals:

H_1 : Arms competitions occur between weapons systems with incompatible policy goals.

H_2 : Arms competitions do not occur between weapons systems with harmonious policy goals.

Hypotheses H_1 and H_2 represent the propositions derivable from the decision-theoretic model as postulated in equation 4. American and Soviet stocks of weapons will be employed to test these hypotheses. The decision-theoretic model, with its focus on the policy characteristics of weapons systems, can be formulated as an n-person general sum game, reducible to a Nash bargaining game for the two nation case (McCubbins, 1979). The objective function in Equation 2 posits that both nations will simultaneously determine their optimal stocks of weapons, given their policy objectives and constraints, and taking into account the simultaneous decisions and policy objectives of their adversary.

Estimation of hypotheses H_1 and H_2 , then, necessitates the estimation of a simultaneous equations system for each pair of opposing weapons systems. The endogenous variables in the following analysis are, then, the actual stocks of various weapons systems deployed by the United States and the Soviet Union in their putative arms competition. The exogenous (independent) variables are the respective GNP's of each nation, where GNP is taken as a proxy for the production, budgetary, and technological constraints of each nation.

TABLE 1 ABOUT HERE

The sample of weapons systems, as listed in Table 1, contains a cross-section of the conventional arsenals of the two superpowers (with the exception of manned strategic bombers, for reasons to be explained below). The sampling reflects the specificity with which the policy characteristics of weapons systems can be identified and the availability of quality time series on each weapons system. Weapons systems with more or less singular policy objectives, and where lengthy enough time series are available for estimation, were selected. On the whole, then, this excludes strategic missiles and naval warships as they serve a multitude of purposes. A multitude of purposes, by itself, however, does not present important theoretical problems, but rather presents problems with identification of the simultaneous system and with estimation of a large number of right-hand side variables with a shortage of degrees of freedom.

Strategic interceptors, surface to air missiles (S.A.M.) and, antitank missiles have very specific and well defined policy missions. Tanks and tactical aircraft have less specifically identifiable policy missions, but it would seem reasonable to expect that their numbers grow in relation to the number of antitank and antiaircraft weapons deployed by their adversary and vice versa. Manned strategic bombers and strategic interceptors present a similar situation; given a policy objective to be fulfilled, the stock of strategic bombers should increase in relation to the deployed stock of strategic interceptors by their adversary.

TABLE 1

SAMPLE OF SOVIET AND AMERICAN WEAPONS SYSTEMS
US STRATEGIC INTERCEPTORS (1964-76) US TACTICAL S.A.M. (1968-76) US TACTICAL AIRCRAFT (1968-76) US HEAVY AND MEDIUM TANKS (1968-76) US ANTI-TANK MISSILES (1966-76) US MANNED STRATEGIC BOMBERS (1964-76)
SOVIET STRATEGIC INTERCEPTORS (1964-76) SOVIET TACTICAL S.A.M. (1968-76) SOVIET TACTICAL AIRCRAFT (1968-76) SOVIET HEAVY AND MEDIUM TANKS (1966-76) SOVIET ANTI-TANK MISSILES (1968-76) SOVIET MANNED STRATEGIC BOMBERS (1964-76)

FIGURES 2, 3 AND 4 ABOUT HERE

Figure 2 displays the relationship between the deployed levels of Soviet heavy and medium tanks and American antitank missiles. The figure suggests that the rapid and exponential deployment of antitank missiles by the United States is in response to the ever increasing number of Soviet tanks deployed. Interestingly, Figures 3 and 4 map mirror images of a disarmament race by the superpowers in manned strategic bombers and strategic interceptors. Possibly instigated by the advent of long range ICBM's and SLBM's, both superpowers, over the period of this study, mothballed large proportions of their deployed arsenals of these weapons systems.

A factor which exerts a clear, and continuous influence upon the American (and thus Soviet) military decision makers, during the period of this study, is the Viet Nam war. The Viet Nam war, by changing the policy objectives of the United States, affected the deployment levels of U.S. weapons stocks. However, the decade of struggle in Viet Nam corresponds, roughly, to the period of study of this paper. Thus, the influence of the Viet Nam conflict is felt, for the most part, continuously throughout the time series. Accounting for the variance provided by the Viet Nam war would therefore not add much predictive power and would subtract from an already precariously low number of degrees of freedom. As such, I chose not to take the Viet Nam conflict into account.

The actual model to be estimated, then, for the testing of hypotheses H_1 , is of the following form (in reduced form):

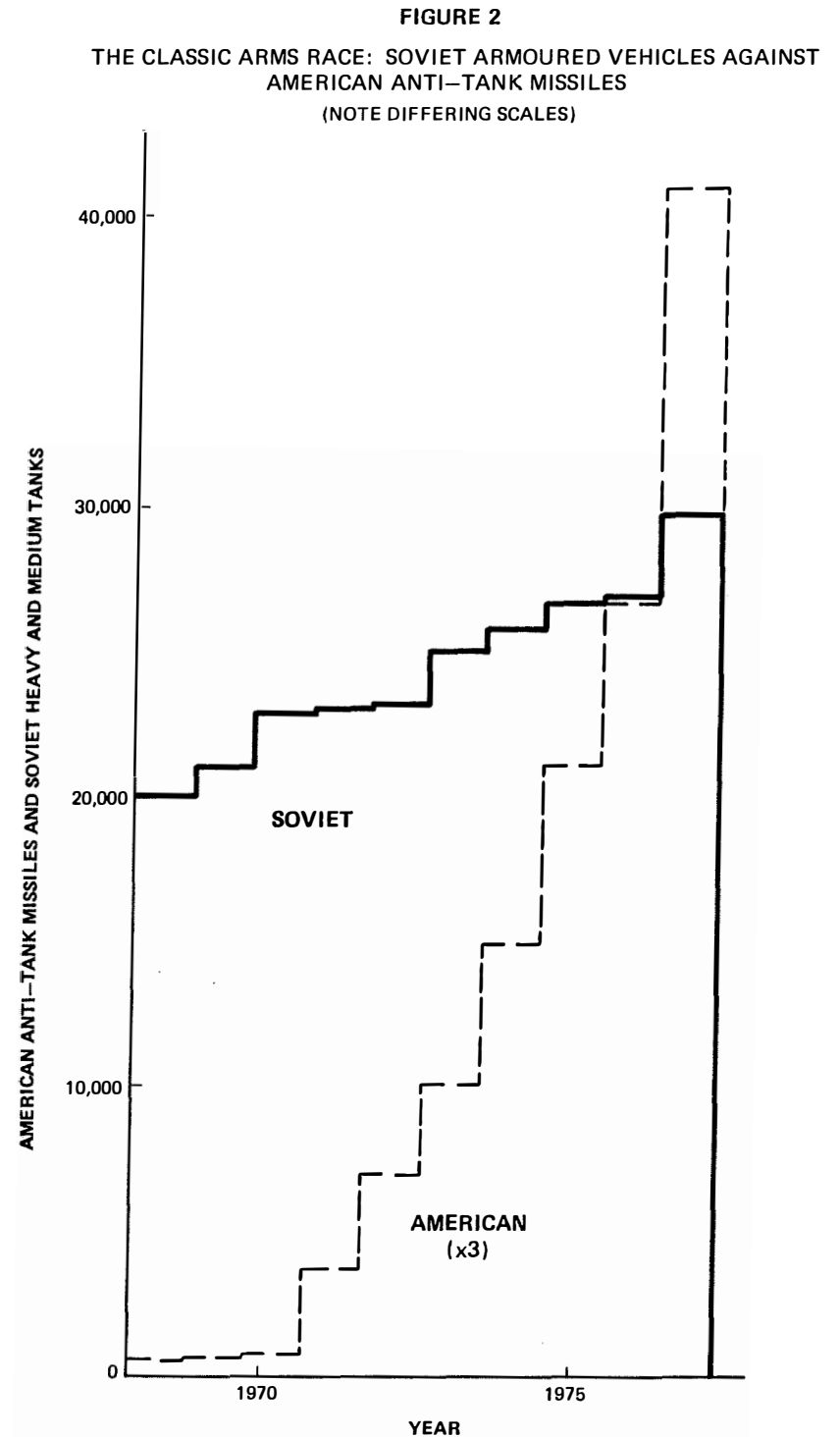


FIGURE 3

THE CLASSIC DISARMAMENTS RACE I: SOVIET INTERCEPTORS
AGAINST AMERICAN BOMBERS
(NOTE DIFFERING SCALES)

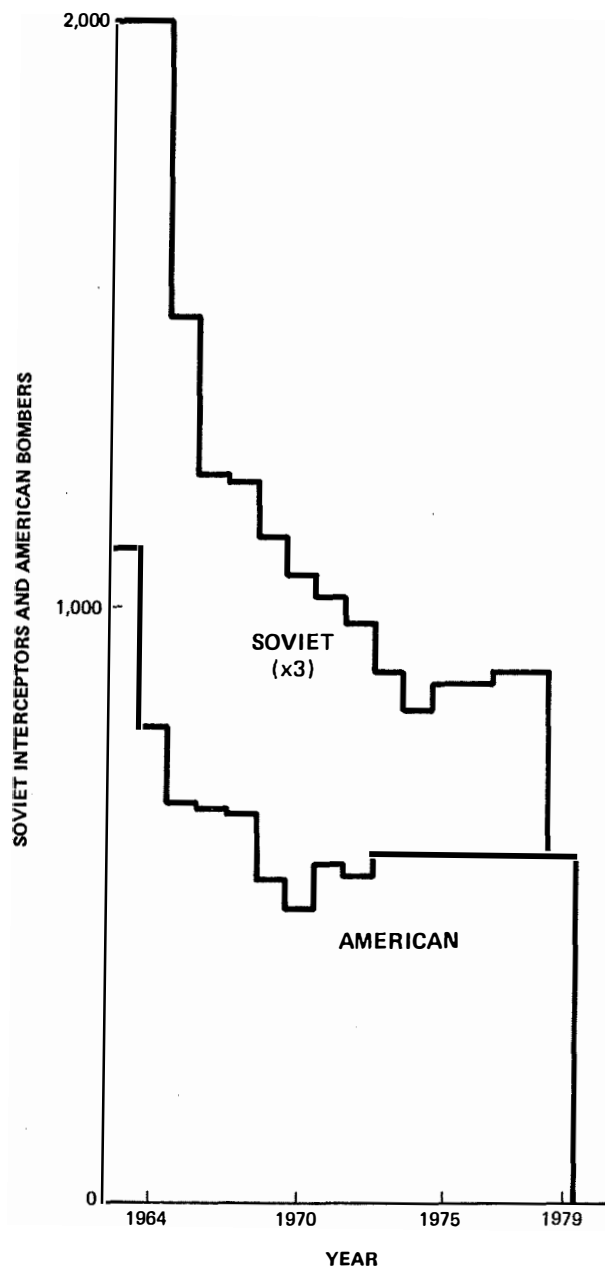
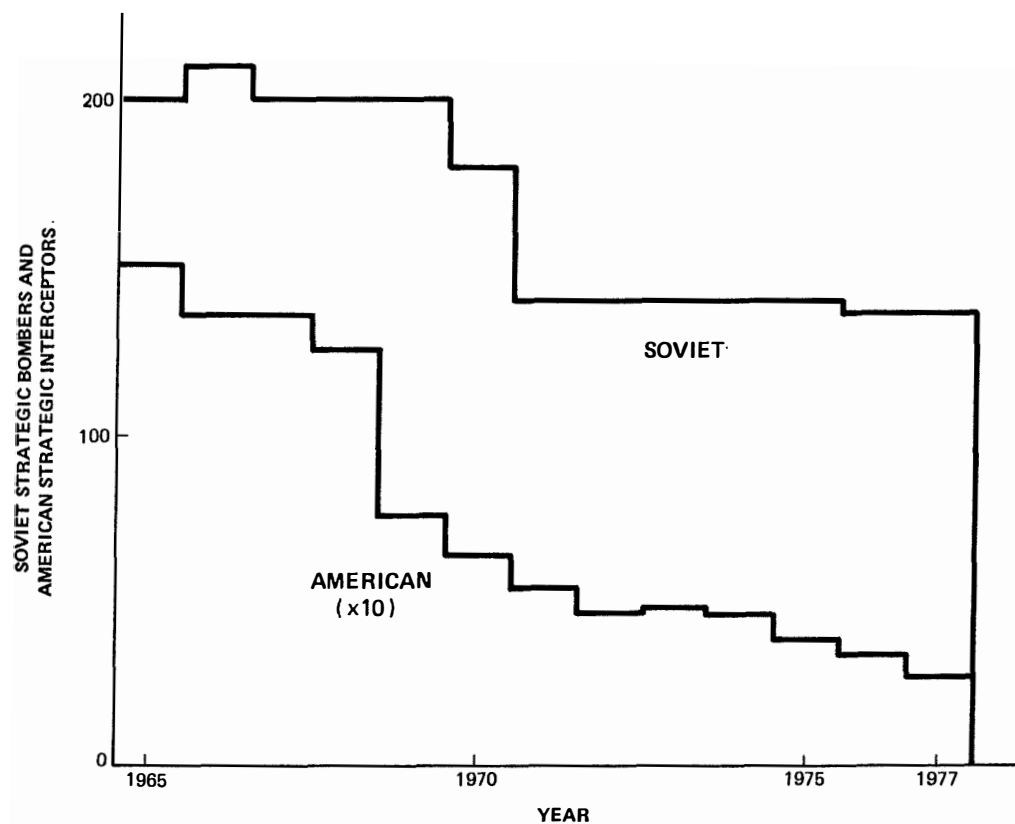


FIGURE 4

THE CLASSIC DISARMAMENTS RACE II: SOVIET STRATEGIC BOMBERS
AGAINST AMERICAN STRATEGIC INTERCEPTORS
(NOTE DIFFERING SCALES)



$$\begin{aligned} w_{us}^1 &= \alpha^1 + \beta_1^1 w_{su}^2 + \beta_2^1 GNP_{us} + u^1 \\ w_{su}^2 &= \alpha^2 + \beta_1^2 w_{us}^1 + \beta_2^2 GNP_{su} + u^2 \end{aligned} \quad (5)$$

where:

w_{us}^1 = the deployed level of weapons system 1, by the US.

w_{su}^2 = the deployed level of weapons system 2, by the Soviet

Union, where the policy goals of weapons system 2 is incompatible with the policy goals of weapons system 1 of the U.S.

α^1, α^2 = constant terms.

GNP_{us}, GNP_{su} = the gross national product of the United States and Soviet Union respectively.

u^1, u^2 = error terms.

The comparative statics of the model in the previous section (summarized in equation 4), from which hypothesis H_1 was deduced, offer clear predictions for the sign of the coefficients, β_1^1 and β_1^2 . The model predicts these coefficients to be positive.

The simultaneous equations system in equation 5 is identified by exclusion restrictions on the exogenous (independent) variables. The coefficients were estimated by the method of two stage least squares. In time series data, however, successive residuals tend to be highly correlated, resulting in biased estimates. The two stage least squares method was therefore augmented by performing a first order autoregressive process (quasi-first difference transformation) to the regression equations. Such a transformation implicitly assumes a first order serial correlation of the residuals.⁵

The results of this analysis are reported in Table 2. The top numbers in each entry are the unstandardized two stage least square regression coefficients, the numbers in parentheses below are the standard errors. Serial correlation may still pose a problem if present. The Durbin-Watson statistics reported in Table 2, though, are quite well-behaved; in only 1 of the 12 equations are they less than 1.5 or greater than 2.5.

TABLE 2 ABOUT HERE

The estimated value of the correlation coefficient (RHO) employed in the first difference transformation was reported for each equation as well. On the whole, these coefficients were small; in only 1 of the 12 equations did the estimated correlation between the untransformed residuals exceed .5 in absolute magnitude.

The figures in Table 2 provide strong support for hypothesis H_1 and the decision theoretic model. Eight of the 12 interactive weapons coefficients were of the predicted sign (positive) and 7 of these were significant at the .05 level. Only 4 were of the incorrect sign and none were significantly different from zero. Moreover, the equations which exhibited coefficients not in line with the predictions of the model were the equations with the smallest degrees of freedom (6 to 8), and thus the results from these truncated time series may not reflect the true underlying relationship.

Interestingly, the estimation did rather poorly, with respect to hypothesis H_1 , on the estimation of the putative arms competition

TABLE 2

TEST OF HYPOTHESIS H ₁							
DEPENDENT ENDOGENOUS VARIABLE	CONST	COEFF OF INDEPENDENT ENDOGENOUS VARIABLE	INDEPENDENT ENDOGENOUS VARIABLE	COEFF OF EXOGENOUS VARIABLE GNP	RHO	d.f.	D-W
US STRAT BOMBERS	70.2 (160.2)	0.10 (0.02)*	SU STRAT INTERCEPT	0.17 (0.08)**	-0.25	10	2.13
SU STRAT INTERCEPT	-50.6 (1724.5)	9.31 (2.30)*	US STRAT BOMBERS	-1.89 (0.44)*	-0.22	10	2.13
US STRAT INTERCEPT	169.6 (726.2)	7.72 (2.87)**	SU STRAT BOMBERS	-0.56 (0.26)**	0.80	10	1.91
SU STRAT BOMBERS	25.3 (65.3)	0.10 (0.03)*	US STRAT INTERCEPT	0.05 (0.04)	0.00	10	1.89
US TACT S.A.M.	-106.2 (482.0)	0.18 (0.02)*	SU TACT AIRCRAFT	-0.26 (0.47)	0.57	6	1.31
SU TACT AIRCRAFT	2250.1 (648.7)*	-1.54 (2.28)	US TACT S.A.M.	2.35 (0.55)*	0.00	6	1.91
US TACT AIRCRAFT	8312.9 (4247.0)*	-0.37 (0.85)	SU TACT S.A.M.	-1.29 (5.04)	0.27	6	1.63
SU TACT S.A.M.	-2296.5 (4407.5)	-0.28 (0.44)	US TACT AIRCRAFT	5.10 (1.56)*	0.25	6	1.67
US H&M TANKS	252.9 (788.0)	0.72 (0.36)**	SU ANTI TANK MISS	-2.17 (1.85)	-0.17	6	1.97
SU ANTI TANK MISS	791.1 (606.7)	0.48 (0.25)**	US H&M TANKS	3.44 (0.22)*	-0.43	6	2.07
US ANTI TANK MISS	274863 (457456)	-166.25 (189.00)	SU H&M TANKS	311.13 (244.00)	-0.15	8	1.69
SU H&M TANKS	2444.1 (264.0)*	0.00 (0.00)	US ANTI TANK MISS	0.94 (0.30)*	-0.49	8	2.23

* COEFFICIENT IS SIGNIFICANT AT THE 0.01 LEVEL
 ** COEFFICIENT IS SIGNIFICANT AT THE 0.05 LEVEL

between American antitank missiles and Soviet heavy and medium tanks, as well as between American tactical aircraft and Soviet surface to air missiles. The lack of supportive evidence from the estimation of these equations is all the more intriguing in light of the appearance of an arms race between American antitank missiles and Soviet tanks in Figure 2. As suggested, however, these equations were estimated from a very small number of observations and the resulting lack of degrees of freedom almost certainly curtailed the convergence of the estimated coefficients.

The production and technology constraint proxy, GNP, does not provide a consistent influence in the estimation of force levels. Though 7 of 12 coefficients are significant, there is no consistent pattern to the signs of the estimated coefficients.

That arms races are evident between pairs of weapons systems deployed for the achievement of mutually incompatible policy goals is also supported by the specification of equation 5 and the evidence in Table 2. Hypothesis H₂ suggests that we should not observe arms competitions between weapons systems whose policy goals are not mutually incompatible. In this regard, recall that Figure 1 had suggested that no arms competition was evident between American and Soviet manned strategic bombers. Indeed, these manned strategic bombers could, all else constant, carry out their policy objectives irrespective of the number of manned strategic bombers deployed by the other side.

Hypothesis H₂ was tested employing the same sample of weapons

systems employed to test hypothesis H_1 . The model to be estimated, to test H_2 , is similar in form to the model estimated to test H_1 :

$$\begin{aligned} w_{us}^1 &= \alpha^1 + \beta_1^1 w_{su}^1 + \beta_2^1 GNP_{us} + u^1 \\ w_{su}^1 &= \alpha^2 + \beta_1^2 w_{us}^1 + \beta_2^2 GNP_{su} + u^2 \end{aligned} \quad (6)$$

where

w_{us}^1 = the deployed level of weapons system 1, by the U.S.

w_{su}^1 = the deployed level of weapons system 1, by the Soviet

Union, of like variety to weapons system 1 of the U.S.

α^1, α^2 = constant terms.

GNP_{us}, GNP_{su} = gross national products.

u^1, u^2 = error terms.

In this system, quantities of like varieties of weapons systems, between the US and USSR, were regressed on one another. It was assumed by this that the policy goals of similar weapons across nations would not be incompatible. However, given the multiplicity of uses and policy objectives of these various weapons systems, such an assumption may indeed be quite strong. However any resulting bias would in fact be disfavorable to the hypothesis under consideration, and so the analysis reported in Table 3 is indeed a strong test of hypothesis H_2 .

Again, to summarize the expectations of hypothesis H_2 , we expect the signs of the interactive weapons coefficients, β_1^1 and β_1^2 , to be nonpositive. The simultaneous equations system in equation 6

was estimated by the method of two stage least squares, adjusted by autoregression transformation to account for the presence of serial correlation. The results of the analysis are reported in Table 3.

TABLE 3 ABOUT HERE

The serial correlation problems posed by the estimation, though more severe than in Table 2, are still quite mild. In only 4 of the 12 equations reported in Table 3 are the Durbin-Watson statistics less than 1.5 or greater than 2.5.

The coefficients reported in Table 3 strongly support the decision theoretic model and hypothesis H_2 . The signs of the coefficients of the interactive weapons term in Table 3 unanimously support the prediction of the model. Though half (6 of the 12) of the coefficients are of the incorrect sign (positive), with respect to hypothesis H_2 , none were statistically significant at the .05 level. The only 2 significant coefficients of the interactive weapons terms were, in fact, negative.

Though previous investigations have cast doubt on the general existence of Richardson arms races, the evidence presented herein suggests that arms competitions, for two mutually antagonistic countries, between weapons systems with mutually incompatible policy goals do in fact exist. Further, the evidence presented suggests that arms competition will occur only between such weapons systems.

In general, the decision theoretic model of armament choice and hypotheses H_1 and H_2 are supported by the tests and model

specification tendered here. Arms competitions, by this analysis, are a reflection of the foreign policy competition between the United States and the Soviet Union. The results of this estimation are all the more impressive given the small number of observations from which the estimates were derived.

TABLE 3

TEST OF HYPOTHESIS H ₂							
DEPENDENT ENDOGENOUS VARIABLE	CONST	COEFF OF INDEPENDENT ENDOGENOUS VARIABLE	INDEPENDENT ENDOGENOUS VARIABLE	COEFF OF EXOGENOUS VARIABLE GNP	RHO	d.f.	D-W
US STRAT BOMBERS	681.6 (662.5)	0.40 (2.71)	SU STRAT BOMBERS	-0.11 (0.20)	0.63	10	1.92
SU STRAT BOMBERS	292.0 (80.9)*	-0.08 (0.09)	US STRAT BOMBERS	-0.07 (0.03)**	0.78	10	1.02
US STRAT INTERCEPT	828.6 (723.7)	0.18 (0.10)	SU STRAT INTERCEPT	-0.61 (0.34)	0.40	10	1.72
SU STRAT INTERCEPT	-1860.0 (5260.8)	4.16 (2.52)	US STRAT INTERCEPT	1.86 (2.92)	0.42	10	1.52
US TACT AIRCRAFT	11388.4 (1816.2)*	-0.87 (0.71)	SU TACT AIRCRAFT	-1.35 (1.76)	0.72	6	1.32
SU TACT AIRCRAFT	2131.9 (5791.8)	-0.01 (0.57)	US TACT AIRCRAFT	1.99 (2.02)	0.21	6	1.67
US TACT S.A.M.	809.9 (762.1)	0.13 (0.16)	SU TACT S.A.M.	-0.59 (0.91)	0.57	6	1.21
SU TACT S.A.M.	-5228.0 (439.0)*	0.64 (1.60)	US TACT S.A.M.	5.93 (0.37)	-0.12	6	1.65
US H&M TANKS	5809.9 (1714.5)*	-2.06 (0.78)*	SU H&M TANKS	2.10 (0.95)*	-0.57	6	1.85
SU H&M TANKS	2775.2 (220.7)*	-0.45 (0.16)**	US H&M TANKS	1.03 (0.08)*	-0.61	6	1.90
US ANTI TANK MISS	-129139 (35769)*	0.24 (25.76)	SU ANTI TANK MISS	140.55 (86.43)	-0.06	6	1.39
SU ANTI TANK MISS	1623.6 (1391.1)	0.00 (0.01)	US ANTI TANK MISS	3.04 (1.53)**	-0.57	6	1.91

* COEFFICIENT IS SIGNIFICANT TO THE 0.01 LEVEL

** COEFFICIENT IS SIGNIFICANT AT THE 0.05 LEVEL

CONCLUSION

A simple model of armament choice, wherein military force level decision makers make tradeoffs between alternative weapons deployments, was developed here to provide a framework for relating the policy characteristics of weapons systems to their deployed levels. The resulting Nash bargaining game and the comparative statics of the optimization problem yielded a refutable hypothesis predicting the nature and structure of armament races: that arms races will occur only between weapons systems with mutually incompatible policy missions.

The simultaneous equations regression analysis reported above generated evidence supportive of the hypothesis that arms competitions exist only between weapons with incompatible policy missions. There did not appear to be any consistent influence from the exogenous variable, GNP, although half (12) of the coefficients from Tables 2 and 3 were significant.

Lastly, the decision theoretic approach enables us to comment on the possibility of effective arms control. Previous arms control measures, such as the SALT I and SALT II agreements, have primarily

established ceiling constraints upon weapons deployments. Such agreements (if enforceable) indeed limit the deployed levels of armaments. However, ceiling constraints act merely to alter the military decision makers' choice set over available weapons systems for which to achieve their defined policy objectives. In this framework, the decision makers will optimize around the constraint, according to their implicit rates of technical substitution between weapons (cf. McCubbins, 1982). The point here is that the addition of a ceiling constraint to the optimization problem defined in equations 2 and 3, by eliminating a specific technology from the armament choice set, may lead to more dangerous, higher technology, arms competitions as the decision makers act to circumvent the arms constraint. It is doubtful, then, that effective arms control is achievable through ceiling constraints.

DATA SOURCES

Data on the weapons stocks of the United States and the Soviet Union was drawn from the following three sources; J. Collins (1978), American and Soviet Military Trends Since the Cuban Missile Crisis (Washington, D.C.: Center for Strategic Studies); Institute for Strategic Studies (1959 to 1977), Military Balance, (London: Institute for Strategic Studies); and the Stockholm International Peace Research Institute (1968 to 1977), World Armaments and Disarmaments, (Cambridge, MIT Press).

GNP figures for the US and the USSR were found in World Armaments and Disarmaments and the Military Balance. The primary functions of weapons systems were drawn largely from Collins and from N. Polmar (1975), Strategic Weapons: An Introduction, (New York: National Strategy Information Center, Inc.).

FOOTNOTES

1. The basic Richardson model is well known (cf. Richardson, 1960; Rapoport 1957, 1960). Other scholars have discussed Richardson stability conditions and have extended the model to a multination case (O'neil, 1970). Alternative models similar to Richardson's have been proposed and the relation between arms races and war initiation have been investigated (Caspary, 1967; Friberg and Jonsson, 1968; Intriligator, 1964).
2. Other problems related to the asymptotic properties of the coefficients of the Richardson model have been discussed elsewhere (Ferejohn, 1976; Schrodtt, 1978).
3. The political gain (or profit) a nation derives from the deployment of a specific weapons system can consist of a combination of foreign policy and domestic political gain. No assumption is made concerning the content of political gain, as it is employed merely to represent the returns a nation receives from weapons deployment.
4. In general, the bureaucratic and organizational approaches to modelling can be based upon models of rational individual behavior, wherein the actor is a bureaucrat, or wherein the organizational structure of the decision making unit influences (or defines) the choices of the individual actors.

5. In equation 5 if the residuals u^1 and u^2 are autocorrelated we can rewrite them as:

$$\begin{aligned} u^{1t} &= \rho u^{1t-1} + e^{1t} \\ u^{2t} &= \rho u^{2t-1} + e^{2t} \end{aligned}$$

where u^{1t} is the residual of equation 1 at time t ,
 ρ is the correlation between the residuals,
 u^{1t-1} is the residual of equation 1 at time $t-1$,
 e^{1t} is the independent residual at time t .

Similarly for u^{2t} , et cetera.

A first difference transformation of equation 5 would then be

$$\begin{aligned} w_{us}^{1t} - \rho w_{us}^{1t-1} &= \alpha^1(1-\rho) + \beta_1^1(w_{su}^{2t} - \rho w_{su}^{2t-1}) + \beta_2^1(GNP_{us}^t - \rho GNP_{us}^{t-1}) + e^{1t} \\ w_{su}^{2t} - \rho w_{su}^{2t-1} &= \alpha^2(1-\rho) + \beta_1^2(w_{us}^{1t} - \rho w_{us}^{1t-1}) + \beta_2^2(GNP_{su}^t - \rho GNP_{su}^{t-1}) + e^{2t} \end{aligned}$$

It should be noted, then, that ρ (RHO in Tables 2 and 3) gives us an indication of the strength of the autoregressive relationship over time.

REFERENCES

- Allison, Graham. 1971. Essence of decision: Explaining the Cuban missile crisis. Boston: Little, Brown.
- Boulding, Kenneth. 1961. Conflict and defense. Boston: Harper and Row.
- Brito, D. and M. Intriligator. 1977. Nuclear proliferation and the armaments race. Journal of Peace Research, 2 (Spring 1977): 231-238.
- Burns, Arthur. 1959. A graphical approach to some problems of the arms race. Journal of Conflict Resolution, 3 (December 1959): 326-342.
- Busch, Peter. 1970. Mathematical models of arms races. In Bruce Russett, What price vigilance? New Haven: Yale University Press: 193-233.
- Caspary, William. 1967. Richardson's model of arms races: Description, critique, and an alternative model. International Studies Quarterly, II (March 1967): 63-68.
- Chatterjee, Partha. 1974. The equilibrium theory of arms races: Some extensions. Journal of Peace Research, 11 (1974): 203-211.
- Collins, J. 1978. American and Soviet military trends since the Cuban missile crisis. Washington, D.C.: Center for Strategic

Studies.

- Ferejohn, John. 1976. On the effects of aid to nations in an arms race. In Dina Zinnes and John Gillespie, eds., Mathematical models in international relations. New York: Praeger: 218-251.
- Friberg, Mats and Dan Jonsson. 1968. A simple war and armament game. Journal of Peace Research, 9 (1968): 233-246.
- Intriligator, Michael. 1964. Some simple models of arms races. General Systems, IX (1964): 143-147.
- , 1975. Strategic considerations in the Richardson model of arms race. Journal of Political Economy, 83 (April 1975): 339-353.
- Intriligator, Michael and D. Brito. 1976. Formal models of arms races. Journal of Peace Science, 2 (Spring 1976): 77-88.
- Lambelet, J. 1976. A complementary analysis of the Anglo-German dreadnought race, 1905-1916. Papers of the Peace Science Society (International), 26 (1976): 219-266.
- Luterbacher, Urs. 1976. Towards a convergence of behavioral and strategic conceptions of the arms race: The case of American and Soviet ICBM build-up. Papers of the Peace Science Society (International), 26 (1976): 1-21.
- McCubbins, Mathew. 1979. A decision-theoretic approach to arms

competition. California Institute of Technology, Social Science Working Paper Number 294, November, 1979.

_____. 1982. Economic models of arms control. Mimeograph, University of Texas at Austin, November, 1982.

McGuire, Martin. 1965. Secrecy and the arms race. Cambridge: Harvard University Press.

_____. 1977. A quantitative study of the strategic arms race in the missile age. The Review of Economics and Statistics, 54 (August 1977): 328-339.

O'neil, Barry. 1970. The pattern of instability among nations: A test of Richardson's theory. General Systems XV (1970): 175-181.

Polmar, N. 1975. Strategic Weapons: An Introduction. New York: National Strategy Information Center, Inc.

Rapoport, Anatol. 1957. Lewis F. Richardson's mathematical theory of war. Journal of Conflict Resolution, 1 (March 1957): 249-299.

_____. 1960. Fights, games and debates. Ann Arbor: University of Michigan Press.

Richardson, Lewis. 1960. Arms and insecurity: A mathematical study of the causes and origins of war. Chicago: Boxwood.

Ruloff, Dieter. 1975. The dynamics of conflict and cooperation between nations: A computer simulation and some results. Journal

of Peace Research, 12 (1975): 109-121.

Russett, Bruce. 1970. What price vigilance? New Haven: Yale University Press.

Saaty, Thomas. 1968. Mathematical model of arms control and disarmament. New York: Wiley.

Schrodt, Philip. 1978. Statistical problems associated with the Richardson arms race model. Journal of Peace Science, 3 (Fall 1978): 159-172.

Taagepera, Rein. 1976. Stockpile-budget and ratio interaction models for arms races. Paper prepared for delivery at the thirteenth Annual European Peace Science Conference, Geneva, Switzerland, August, 1976.

Taagepera, R.; G. Shiffler; T. Perkins; and D. Wagner. 1975. Soviet-American and Israeli-Arab arms races and the Richardson model. General Systems, 20 (1975): 151-158.

Wallace, Michael. 1979. Arms races and escalation. Journal of Conflict Resolution, 23 (March 1979): 3-15.

Zinnes, Dina and John Gillespie, eds. 1976. Mathematical models in international relations. New York: Praeger.